**International Journal of Mechanical Engineering and Technology (IJMET)**
Volume 9, Issue 11, November 2018, pp. 2042–2047, Article ID: IJMET_09_11_215
Available online at http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=9&IType=11
ISSN Print: 0976-6340 and ISSN Online: 0976-6359



# IMPROVEMENT OF AIR BLAST SUPPLY OF UPRIGHT CONVERTER

**Viktor Mikhailovich Sizyakov, Georgii Vladimirovich Konovalovand Tatyana ReonaldovnaKosovtseva**

Saint Petersburg Mining University,
Saint Petersburg, Russia

**ABSTRACT**

*Hydrodynamics of oxygen upright converter has been estimated by physical and mathematical simulation. A new method of air blast supply based on the design of jet spinning apparatus is proposed. Ultimate blast loads have been determined. Possibility in principle has been demonstrated of significant increase of unit power of upright converter by means of spatially oriented blast supply and release of additional heat energy in amount of 4.5 GJ per one converter cycle. The associated technical effect is comprised of increased efficiency of reprocessing of secondary iron scrap and reduced load on dust cleaning system due to kinetic energy of blast spatially oriented jets.*

**Key words:** LD Converter, Top Blowing, Spatially Oriented Blowing, Hydrodynamics, Blast Supply, Ultimate Blast Load, Cast Iron, Simulation.

**Cite this Article:** Viktor Mikhailovich Sizyakov, Georgii Vladimirovich Konovalovand Tatyana ReonaldovnaKosovtseva, Improvement of Air Blast Supply of Upright Converter, International Journal of Mechanical Engineering and Technology, 9(11), 2018, pp. 2042–2047.
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=9&IType=11

## 1. INTRODUCTION

Any metallurgical process is based on combination of regularities of technological process characterized by certain properties with operation conditions of respective metallurgical apparatus. Diversity of properties both of numerous metals and of mineral raw stuff used for their smelting predetermines numerous designs of metallurgical furnaces and their operation conditions.

Difficulties of development of theoretical aspects of furnace technology are stipulated by the fact that operation of any metallurgical furnace is combined of several closely interrelated processes and at the same time obeying their own physical essence. The following five processes are considered to be the most important [1]:

1) Technological process: combination of all physicochemical transformations of initial blend materials under the impact of respective temperature and existence of any reagents;

2) Energy process: production of heat energy required for technological process;

3) Heat exchange process. Total heat consumption for technological process and heat efficiency of this furnace depend on intensity of heat exchange in furnace operation space and on heat exchange between the furnace and ambient environment;

4) Gas dynamic process: motion of technological gases in furnace operation space, its gas ducts, external gas and air supplies, and other facilities. A specific type of gas dynamics peculiar for metallurgical furnaces is jet mode of gas outflow from holes and tips under pressure;

5) Mechanical process: motion of solids and liquids in the furnace. This motion appears due to direct action of gravitation forces, spinning of furnace shell, direct action of gas jets, etc. Any mechanical process is intended for certain modification of technology, energy performances, heat exchange in furnace.

Hence, designing and construction of furnaces, prediction of their operation modes should be based on the basis of concept of the so called limiting process selected for predetermined technological process from other four aforementioned processes in accordance with actual features of this or that furnace.

In upright converters applied in ferrous metallurgy upon achievement of certain critical blast rate there occur massive splashes of melt from apparatus, that is, mechanical process will be limited. Aiming at quantitative estimation of ultimate blast rate and possible increase of this property for upright oxygen converter we apply mathematical and physical simulation. With the aim of comparison let us consider unit upright blast supply via de Laval nozzle and the novel spatially oriented blast supply via radial axial tuyeres [2, 3].

## 2. METHODS

Let us consider hydrodynamics in operation space of 30-ton upright converter. Geometrical sizes are determined by detailed drawing in full scale. Numeric simulation of two-phase medium was performed in ANSYS CFX. The calculations were based on the *SST* model (shear stress transport) of turbulence which was efficient in computations of detached flows. The *SST* model is based on k-ω linear combinations in near surface regions and k-ε models far from the surfaces [4, 5].

In stationary mode the *SST* model is as follows:

$$\frac{\partial \rho k u_i}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right) + \rho P_k - \rho C_\mu k\omega$$

$$\frac{\partial \rho \omega u_i}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\left(\mu + \frac{\mu_t}{\sigma_\omega}\right)\frac{\partial \omega}{\partial x_i}\right) + (1 - F_1)2\rho\frac{1}{\sigma_\omega \omega}\frac{\partial k}{\partial x_i}\frac{\partial \omega}{\partial x_i} + \alpha\frac{\omega}{k}\rho P_k - \rho\beta\omega^2$$

where$\mu_t = \rho\frac{\alpha_1 k}{max(\alpha_1\omega, |\bar{S}|F_2)}$ is the turbulent viscosity; $\rho P_k = min(\mu_t|\bar{S}|^2, 10C_\mu k\rho\omega)$ is the generation of kinetic energy; $\sigma_k$,$\sigma_\omega$,$\alpha$and$\beta$ are the coefficients calculated as $\Phi = F_1\Phi_1 + (1 - F_1)\Phi_2$, $\Phi_1$and$\Phi_2$ are the coefficients of the k-ω and k-ε model,$C_\mu$= 0.09,$\alpha_1$ = 5/9, $\alpha_2$ = 0.44,$\beta_1$ = 0.075, $\beta_2$ = 0.0828,$\sigma_{k1}$ = 2, $\sigma_{k2}$ = 1,$\sigma_{\omega 1}$ = 2, $\sigma_{\omega 2}$ = 1/0.856, $F_1$ and$F_2$ are the toggling functions determined as follows:

$$F_1 = \begin{cases} 0, & \text{far from surface}, k - \varepsilon \text{ model} \\ 1, & \text{in boundary layer}, k - \omega \text{ model} \end{cases}$$

$$F_2 = \begin{cases} 0, & \text{combination of the } k - \varepsilon \text{ and } k - \omega \text{ models} \\ 1, & \text{the } SST \text{ model} \end{cases}$$

The following assumptions are made: the process is adiabatic, isothermal, without internal heat sources and chemical transformations; the inlet and outlet gas flow rates are equal, no liquid phase is removed. Such formulation of the mathematical simulation makes it possible to reduce the time of computations.

The initial parameters of the mathematical model are summarized in Table 1.

**Table 1** Parameters of SST model

| Parameter | Value | Units |
|---|---|---|
| Melt density | 5,000 | kg/m$^3$ |
| Gas density upon outflow | 1.2 | kg/m$^3$ |
| Converter internal space | 18 | m$^3$ |
| Coefficient of filling with gas | 0.2 | - |
| Distance from tuyere tip | 0.8 | m |
| Mass gas flow rate | 1.5; 3.0; 9.0 | kg/s |
| Volumetric flow rate | 1.25 | m$^3$/s |
| Blast load | 75 | m$^3$/min |
| Specific blast load | 4.2 | m$^3$/m$^3$min |

## 3. RESULTS AND DISCUSSION

Results of the numerical simulation are illustrated in Figure 1 where: 1, 2 are the blast supply by single upright tuyere with mass gas flow of 1.5 and 3 kg/s, respectively; 3, 4 are the supply of spatially oriented blast with mass gas flow of 3 and 9 kg/s, respectively, by five radial axial tuyeres.

Gas flow rate as a function of blast rate is indicated by colors in longitudinal and upper transversal cross sections. Here the gray scales show the gas flow rate in the range from 0 to 10 m/s, the flow lines show the motion direction of liquid phase. The first image illustrates hydrodynamics under operation conditions, and the second image – in excess of ultimate blast load.

The dynamics of blast crater are formed under conditions of complex spatial interaction of forces of dynamic pressure of jets directed downwards, forces of gas floating directed upwards, and forces of thermal expansion of gases (not accounted in the computations) acting in all directions. Due to unbalanced impact of these forces the crater is in the state of stochastic surges from side to side (detected upon animation of calculation at increment of 0.5 s). Massive splashes are generated from the crater by upper gas flow which requires to raise tuyere to significant distance of 0.5–1.0 m from the bath surface aiming at safety, thus decreasing the effect of jet penetration into the melt. Disordered surges of high temperature crater reach side walls of the apparatus destroying them. At other segments of refractory brickwork, to the contrary, ledges can be formed which distort ordered heat exchange even more. Blast loads exceeding ultimate levels promote formation of massive melt splashes from furnace operation space increasing the crater depth, and form low temperature crater in the vicinity of converter lining which leads to its thermal destruction.

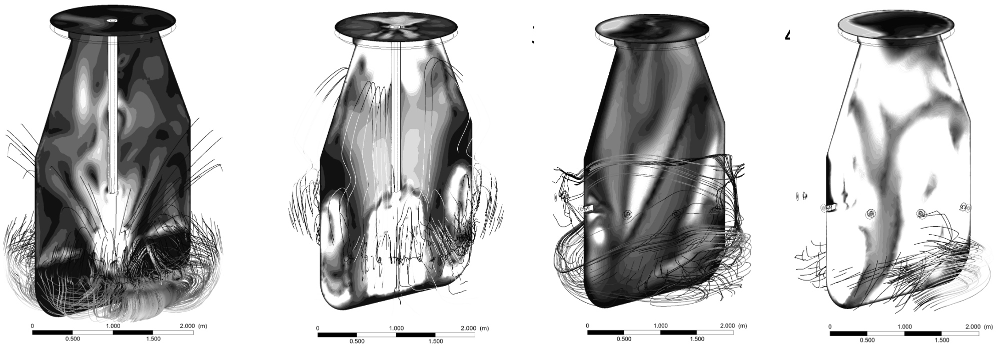

**Figure 1** Hydrodynamics of converter

Figure 1 (2) shows nearly upright splash of liquid phase from operation space. Since the dynamic gas head in the upper part of converter increases according to continuity law, due to narrowing at equal flow rate, in reality the flow line should leave the neck boundaries. Certain distortion is caused by assumption of absence of outflow of liquid phase in nonstationary mode.

Another situation is observed in the case of spatially oriented blast supply arranged by means of several tuyeres located horizontally in the converter wall along the arc of 120° (Figure 1, (3), (4)). Here the colors show the gas flow rate in the range from 0 to 20 m/s.

The blast jets outflowing at the angle of 30° to the bath surface generate wave which upon impingement with cylindrical wall adds spinning motion to the melt, and the gas phase acquires cyclone effect decreasing the vertical projection of vector of melt motion from the operation space of apparatus. Therefore, the blast load can be multifold increased without significant melt splashes, which is also confirmed by physical simulation of converter bath using water and air as model fluids (Figures 2, 3).

The physical model at the scale of 1:10 with the filling coefficient of 0.25 was tested with two variants of blast supply by single upright tuyere and spatially oriented six radial axial mini-tuyeres. In the first variant the specific blast load was 6 $m^3/m^3$min, its ultimate value was achieved, in the second variant –36 $m^3/m^3$min without noticeable splashes.

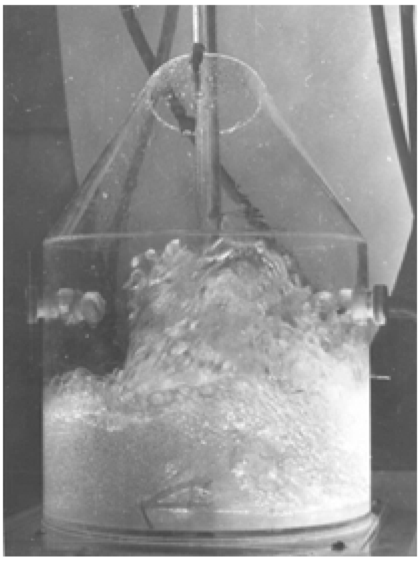

**Figure 2.** Bath behavior with top blowing. Flow rate: 0.4 $m^3$/min.

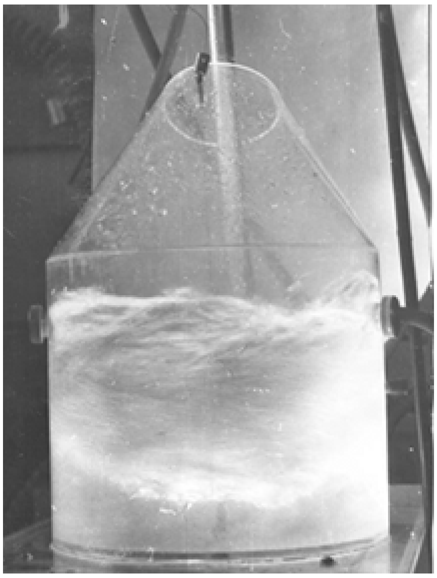

**Figure 3.** Baht behavior with spatially oriented blowing. Flow rate: 2.4 $m^3$/min

Generalized results of physical simulation of the upright blast supply and the alternative variant are summarized in Table 2.

Therefore, mathematical and physical simulation proved possibility to increase specific blast load by 4–6 times with spatially oriented blast supply. However, despite the hypothetical possibility of multifold increase of specific blast load, probably, it would be reasonable to be restricted with its two-fold increase, which is related with kinetic difficulties of process chemical reactions and required reserve of the unit converter capacity.

**Table 2.** Comparison of blast supply methods

| Fig. No. | Blowing | Specific blast supply, m3/m3min | Remark |
|---|---|---|---|
| 1 | top | 4.2 | No upright splashes |
| 2 | | 6.0-8.3 | Achievement of ultimate blast load |
| 3 | spatially oriented | 8.3 | No upright splashes, cyclone effect is observed |
| 4 | | 25-36 | |

Taking into consideration nearly complete acquisition of blast oxygen by melt in steel smelting converter, it is possible to suggest direct dependence between blast supply amount to melt and converter capacity, hence, it follows that unit capacity of upright converter can be significantly increased by spatially oriented blast supply. Since the spinning motion of overall melt bulk occurring under the action of spatially oriented jets is the closest to apparatus of ideal mixing, certain kinetic restrictions can be neglected upon exchange interaction and slag formation.

Increased converter capacity will be accompanied with variation of heat balance structure, namely, decrease in heat release to ambient environment in amount equivalent to increase in capacity, since this is the only item of heat balance depending on converter capacity.

Then, for 300-ton oxygen upright converter the ambient heat loss is about 2% or, in absolute values, about 30 MJ per one ton of cast iron. Since this is the only item of heat balance depending on converter capacity,it is possible to give preliminary estimation of heat efficiency resulting from implementation of spatially oriented blast which will be 15 MJ per one ton of cast iron or 4.5 GJ per one cycle of conversion of 300 tons of cast iron during 50 min or 5.4 GJ per hour. Such reserve of heat energy can be additionally used, for instance, upon addition of 3 tons of cold secondary materials or scrap into converter with accounting for heat consumption of final products in amount of 1.5 GJ/th.

Cyclone effect formed in gas phase above the melt level upon spatially oriented blast supply will suppress dust emissions from operation space of oxygen upright converter.

## 4. CONCLUSION

The technical effect of fundamentally new spatially oriented blast is achieved by increase in blast load onto upright converter, intensive spinning of melt bulk in overall space of the apparatus created by dynamic pressure head of blast jets and cyclone effect of gas phase, herewith about 1% of heat energy is released which can be used for processing of secondary raw stuff, and the cyclone effect promotes reduction of dust emissions and decrease in load on dust cleaning system.

## REFERENCES

[1] Diomidovskii, D.A. *Metallurgicheskiepechitsvetnoimetallurgii* [Furnaces of nonferrous metallurgy]. Guidebook. 2nd edition, revised and supplemented. Moscow: Metallurgizdat, 1970.

[2] Sizyakov, V.M.andKonovalov, G.V. Space-oriented unsubmerged streams as a basis of new autogenous apparatus design. *TsvetnyeMetally*, **10**, 2016,pp. 14-20

[3] Konovalov, G.V., Kosovtseva, T.R., Tsybizov, A.V. andAmosova, A.P. Studies of the hydroaerodynamic characteristics of a radial-axial lance.*Metallurgist*, 59(7–8),2015,pp. 631-636.

[4] Menter, F. R. Two-equation eddy-viscosity turbulence models for engineering applications.*AIAA Journal*,**32**(8),1994, pp. 1598–1605.

[5] Menter, F. R., Kuntz, M. and Langtry, R. Ten Years of Industrial Experience with the SST Turbulence Model. *Turbulence, Heat and Mass Transfer,***4,**2003,pp. 625–632.